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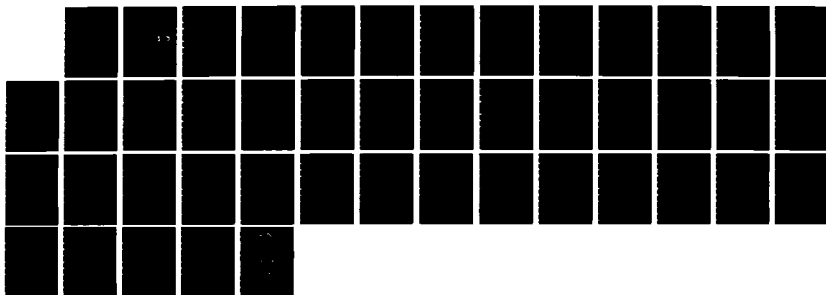
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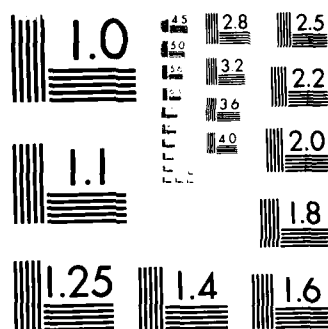
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Analysis of a Linear Antenna Two Wavelengths Long: Consideration of Options

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I. INTRODUCTION

For many electromagnetic problems that require a rigorous solution for the electric field, a closed-form analysis is impractical because of the complexity of the integrals involved. On the other hand, the computer approximation of these problems is generally easy and accurate.

An approximation method that is extensively used in the community is the method of moments.¹ The method of moments reduces a nonlinear equation to a set of linear equations that can be solved by matrix methods such as Gaussian elimination and conjugate gradients.^{2,3} In this report, the method of moments is applied to Pocklington's integral equation to approximate the electric field radiated by a wire dipole antenna two wavelengths long.

II. PROBLEM FORMULATION

In order to compute the far-field pattern from the dipole, the procedure is first to compute the current on the wire by the method of moments and then to integrate the current using the Green's function. The method of moments can be used to approximate the current on the wire as pulses at discrete positions on the wire. The distances between these pulses are arbitrary but, for programming ease, they should be uniform. The model that is developed for the dipole antenna is a wire divided into an integral number of segments with half-segments at the ends where the current is zero. The pulse approximation dictates that the values for the current and the voltage on each segment be constant. The current and voltage can be represented as twin arrays, with each element of an array corresponding to the value either of the current or the voltage on a segment. For the center-fed dipole antenna, as shown in Figure 1, the values for the elements of the voltage array are zero, except that the element corresponding to the center segment has the value of the voltage applied, V_A . The values of the elements of the current array are the unknowns in the dipole antenna problem.

The number of segments is critical to the resolution of the current. A rule of thumb is to select at least 10 segments per wavelength. For example, if the antenna is 0.5λ long, then at least five segments are required. The overall size of the dipole antenna to be analyzed is limited by the number of segments that can be treated practically. For antenna structures that are more general than a simple linear dipole, the two-dimensional current distribution, rather than axial dipole current, must be obtained. Thus, the overall size of the antenna structure is limited to designs that are small in terms of wavelengths.

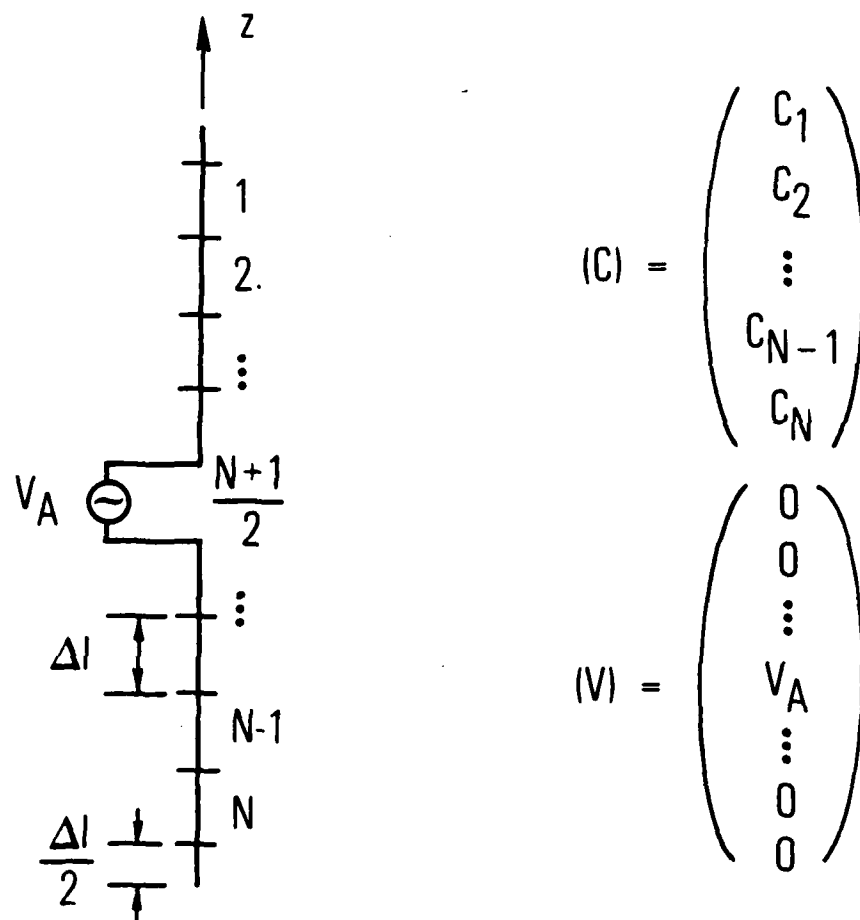


Figure 1. Center-Fed Dipole Antenna with N Segments. Array elements represent the current and voltage on the segments.

III. METHOD OF MOMENTS

The pulse model of the dipole antenna is implemented in the method of moments by using the pulse function

$$P(z, z_n) = \begin{cases} 1 & |z - z_n| < \frac{\Delta l}{2} \\ 0 & \text{elsewhere} \end{cases}$$

as a basis function. Because z_n denotes the center of the n th segment and Δl is the length of the segment, the pulse function is zero except at the n th segment. Other basis functions that are appropriate for modeling the dipole antenna are the sinusoidal and triangular functions. The equation to be linearized in the wire antenna problem is Pocklington's integral:

$$\left(k^2 + \frac{\delta^2}{\delta z^2}\right) \int_0^L C(z') G(z, z') dz' = -j\omega 4\pi\epsilon_0 E_{\tan}^i(z)$$

where z' , the integration point, is the position of the current on the wire; z , the observation point, is the position of the impressed electric field on the wire; and $G(z, z')$ is the Green's function for a thin wire antenna of radius a :

$$G(z, z') = \frac{\exp\{-jk[a^2 + (z - z')^2]^{1/2}\}}{\sqrt{a^2 + (z - z')^2}}$$

The current on the wire, $C(z')$, is the unknown for which the moment method will approximate a solution. The observation points are selected to be on the surface of the wire, where the expression for the impressed electric field is valid, and the integration points are on the axis of the wire. The first step of the moment method is to write $C(z')$ in terms of the basis function:

$$C(z') = \sum_{n=1}^N C_n P(z', z_n)$$

If we bring the second derivative inside the integral in accordance with Pearson,⁴ the Pocklington's integral becomes

$$\sum_{n=1}^N C_n \int_{z_n - \frac{\Delta l}{2}}^{z_n + \frac{\Delta l}{2}} (k^2 G + \frac{\delta^2 G}{\delta z^2}) dz' = -j\omega 4\pi\epsilon_0 E_{\tan}^i$$

This simplified equation can be linearized by using a Dirac delta function as the testing function. This changes Pocklington's equation to

$$\sum_{n=1}^N C_n \int_{z_n - \frac{\Delta l}{2}}^{z_n + \frac{\Delta l}{2}} \{k^2 G(z_m, z') + [\frac{\delta^2}{\delta z^2} G(z, z')]_{z=z_m}\} dz' = -j\omega 4\pi\epsilon_0 E_{\tan}^i(z_m).$$

The second derivative can be evaluated two ways - analytically and by finite differences. The difference between the far-zone electric field of the analytical and finite differences is minimal, as is shown in the numerical results section of this report. However, the current at the center of the wire and, therefore, the input admittance, do not agree.

The resultant matrix equation, $[Z][C] = [\Delta l \cdot E]$, can be solved for the unknown current by standard matrix inversion methods, such as Gaussian elimination and L-U factorization or by the conjugate gradient method. The conjugate gradient method is discussed subsequently because it is not as universally used as the other methods and because it requires less memory.

IV. CONJUGATE GRADIENT METHOD

The conjugate gradient method is an iterative method that assumes a solution and, by computing the residual, adjusts the initial solution until the relative error is within the specified tolerance. The method is best used to minimize or maximize an optimization function but can also be used, as in this case, to solve a linear equation. The conjugate gradient algorithm is as follows:^{2,3}

$$r_0 = ZC_0 - V$$

$$P_0 = -b_{-1} Z^* r_0$$

$$C_{k+1} = C_k + t_k P_k$$

$$r_{k+1} = r_k + t_k Z P_k$$

$$P_{k+1} = P_k - b_k Z^* r_{k+1}$$

$$t_k = \frac{1}{|Z P_k|^2}$$

$$b_k = \frac{1}{|Z^* r_{k+1}|^2}$$

where

$$V = [\Delta l \cdot E]$$

Z^* = the complex conjugate of the impedance matrix

The algorithm computes the residual array, r_k , at each iteration and makes adjustments to the current array, C_k , based on the residual array to minimize the relative error. The expression for the relative error is $|ZC_k - V|/|V|$. If the current is initially assumed to be zero at every segment, the error equals 1 at the first iteration and decreases monotonically, until the error is less than the prescribed tolerance. For the problem of the wire antenna

two wavelengths long, a tolerance of 10^{-8} was used, and the algorithm converged within a reasonable number of iterations. A chart of the convergence rate is shown in the numerical results section of this report.

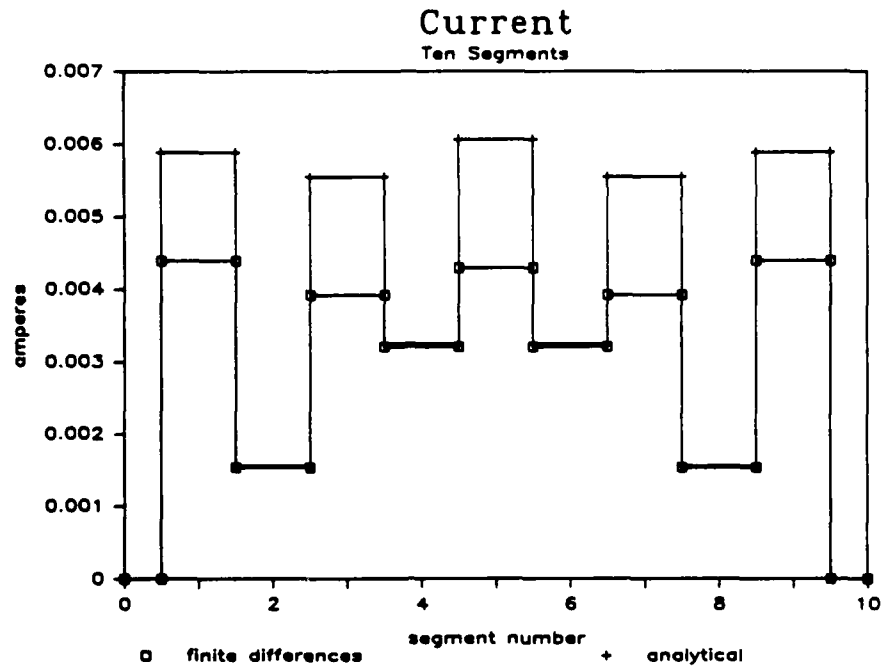
The memory requirement for the conjugate gradient method is $7N$, as opposed to $2N^2 + 2$ for the IMSL library routine that was used to verify the results presented in this report.

V. NUMERICAL RESULTS

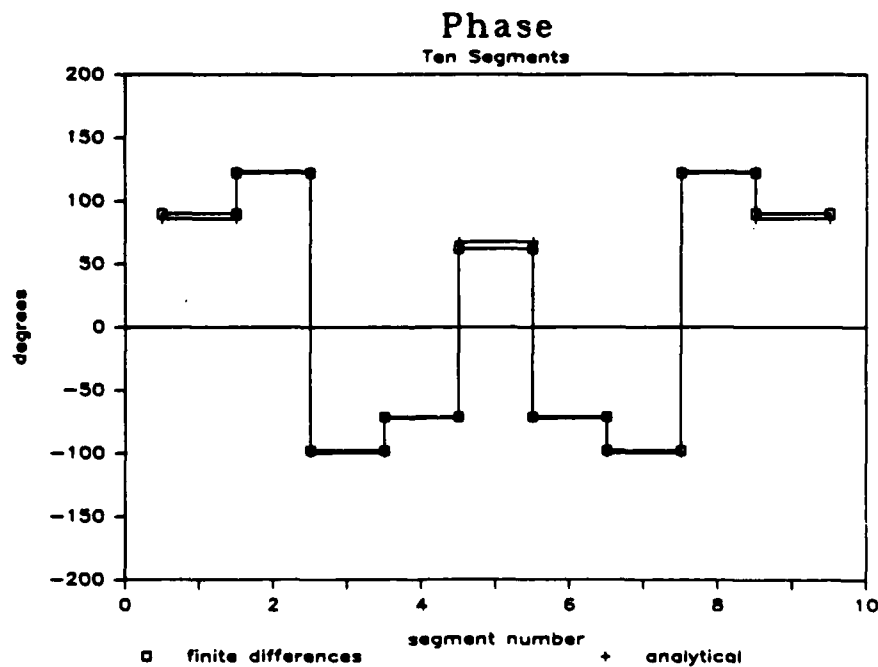
The numerical results reported in the tables and figures of this section are illustrations of the comparison of four combinations of second derivative methods with linear equation methods: (1) analytical derivative with conjugate gradients, (2) analytical derivative with L-U decomposition, (3) finite differences with conjugate gradients, and (4) finite differences with L-U decomposition. (The listings for the computer programs written in-house are given in the Appendix.) The combinations were applied to a theoretical wire antenna with a length of 2λ and a radius of 0.013λ , with 1 V applied to the center. Because an error tolerance of 10^{-8} was set for the conjugate gradient method and 10^{-14} for the L-U decomposition, the current, far-zone electric field, and input admittance calculated by each of these matrix methods for the same second derivative method are equal to at least eight significant figures. Because the numerical values calculated by the conjugate gradient method and L-U decomposition are equivalent, no distinction is made between them in Figures 2, 3, and 4 or in Tables 1 and 2.

Figures 2, 3, and 4 illustrate the trends of the current approximated by the analytical derivative and by finite differences as the number of segments is increased from 10 to 20 and then to 60. Assuming that the current approximated by 60 segments is close to an actual experimental sampling at those segments, we can deduce, from the plots of the approximations with 10 and 20 segments, that 10 segments is not sufficient and that 20 segments is sufficient. In fact, if we were able to superpose the plot with 20 segments over the one with 60 segments, we would see that they were very close in numerical value but that the one with 20 segments had less resolution.

The electric field, at a distance of 50 wavelengths, calculated from the approximations of the currents on 20 segments, is shown in Table 1. The differences in the electric fields are within 0.2 dB for the main lobes and 2 dB for the low-power angles.

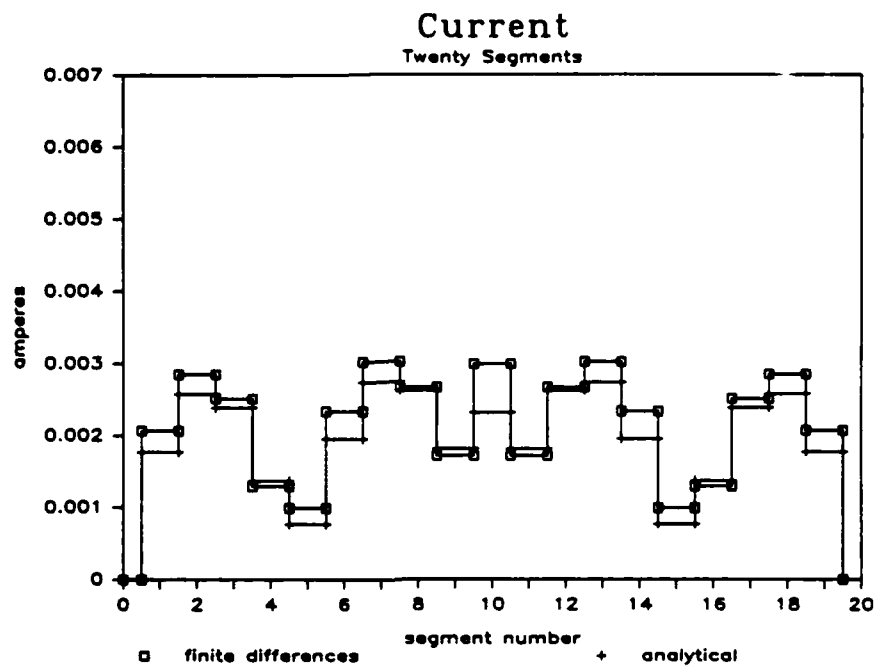


(a)

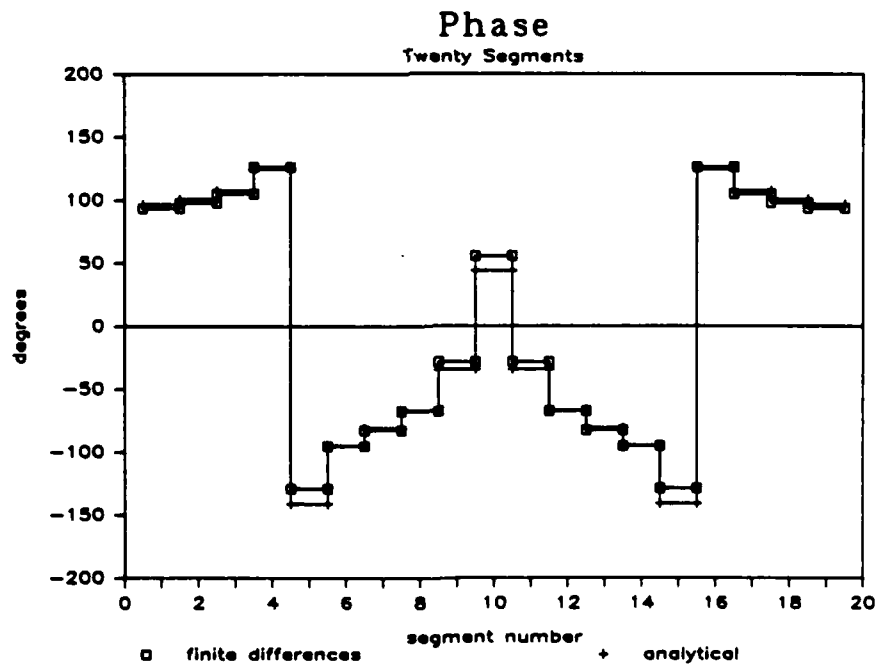


(b)

Figure 2. Ten Segment Approximation. Amplitude and phase of the current on a center-fed antenna two wavelengths long, 0.013 wavelengths in radius with 1 V applied.

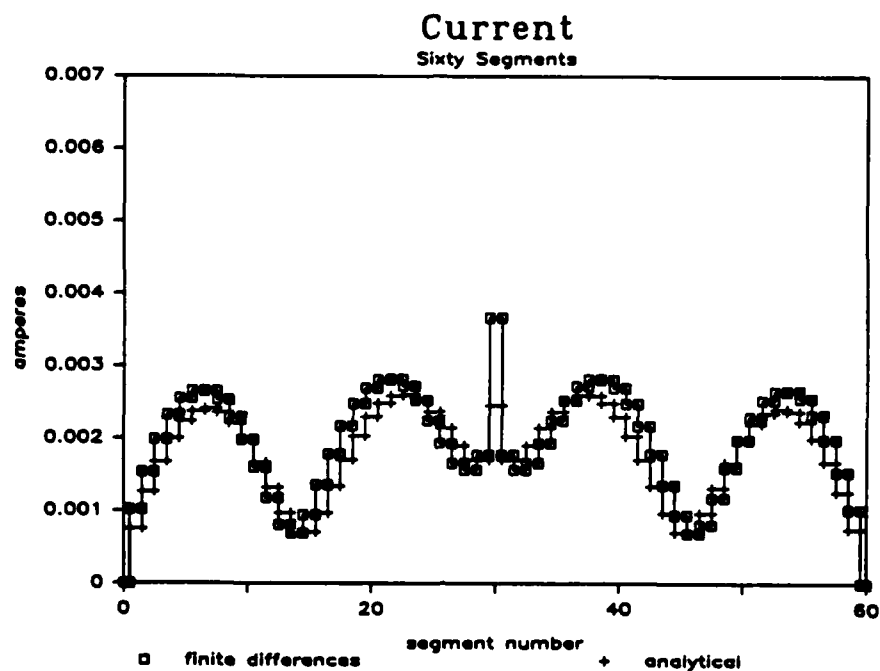


(a)

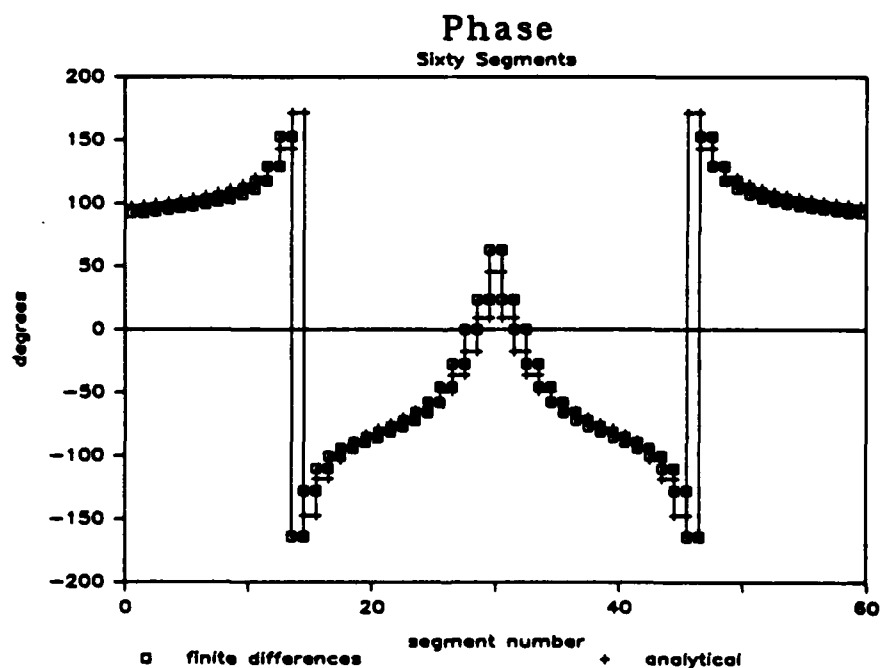


(b)

Figure 3. Twenty Segment Approximation. Amplitude and phase of the current on a center-fed antenna two wavelengths long, 0.013 wavelengths in radius with 1 V applied.



(a)



(b)

Figure 4. Sixty Segment Approximation. Amplitude and phase of the current on a center-fed antenna two wavelengths long, 0.013 wavelengths in radius with 1 V applied.

Table 1. Far-Zone Electric Field

Angle (deg)	Finite Differences (dB)	Analytical (dB)
10	-3.4	-5.3
20	1.0	+0.3
30	5.5	6.3
40	11.7	12.2
50	15.8	15.9
60	17.0	16.8
70	14.4	14.2
80	5.7	5.8
90	-2.3	-3.8

Although the agreement of the far-zone electric field is adequate, the admittance calculated with analytical derivatives and finite differences yields approximately 23 percent difference in magnitude. This magnitude difference for the 2λ antenna is in the same range of differences reported by Butler and Wilton⁵ for a 1.5λ antenna. The value of the input admittance is important for matching. The result for 20 segments are given in Table 2.

Table 2. Input Admittance

REAL	
Finite differences	1.687 mmhos
Analytical	1.668 mmhos
IMAGINARY	
Finite differences	2.466 mmhos
Analytical	1.609 mmhos

The calculations were executed with ANSI Standard Fortran 77 on the CDC Cyber 176. Two matrix routines were used to find the solution of the matrix equation: (1) the conjugate gradient algorithm described in this report and (2) an IMSL library routine that uses L-U decomposition and iterative

improvement. The execution time varied with the method used for the linear equation solution and the method used for evaluating the second derivative of the Green's function. For the second derivative evaluated by finite differences on a wire approximated by 20 segments, the times for different linear equation methods are given in Table 3.

Table 3. CPU Times for Finite Differences

Conjugate gradient	2.3 cpu sec
L-U decomposition	1.9 cpu sec

The times for different second derivative methods using the conjugate gradient method are given in Table 4.

Table 4. CPU Times for the Conjugate Gradient Method

Finite difference	2.3 cpu sec
Analytical derivative	5.3 cpu sec

The times given in Tables 3 and 4 are the total cpu times for calculating the current, input admittance, and far-zone electric field. Execution times for the conjugate gradient method were made with an initial current of zero at every segment. Because the conjugate gradient method is iterative, the execution time depends upon the residual computed from the initial current array.

For this antenna, for which the current is symmetric about the center segment, the conjugate gradient method arrived at a solution in $N/2$ iterations. In Figure 5, the logarithm of the relative error is shown versus the iteration number for 10, 20, and 60 segments. The relative error approaches the tolerance of 10^{-8} monotonically in each case.

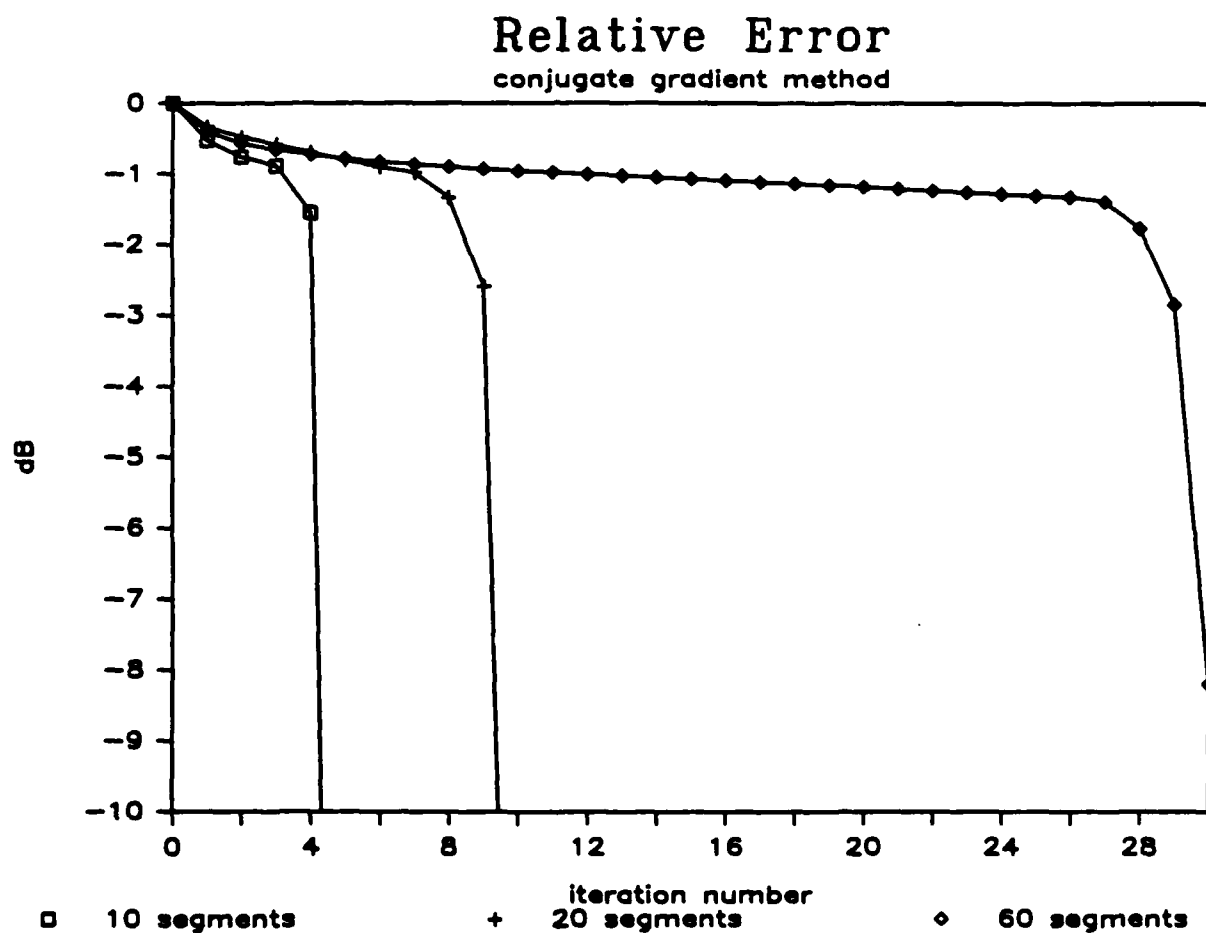


Figure 5. The Logarithm of the Relative Error Versus the Number of Iterations of the Conjugate Gradient Algorithm for 10, 20, and 60 Segments

VI. CONCLUSIONS

In this report, the numerical methods are discussed for analyzing a linear antenna using the method of moments. Within the method of moments there are several options to consider: which basis and testing functions to use, how to evaluate the second derivative, and which linear equation method to use. The criteria used in selecting the options may be as follows:

1. Agreement of numerical results with previously accepted results.
2. Ease of implementation.
3. Computer execution time.
4. Computer memory requirements.

A summary of the options discussed in this paper and how they meet the criteria is given subsequently.

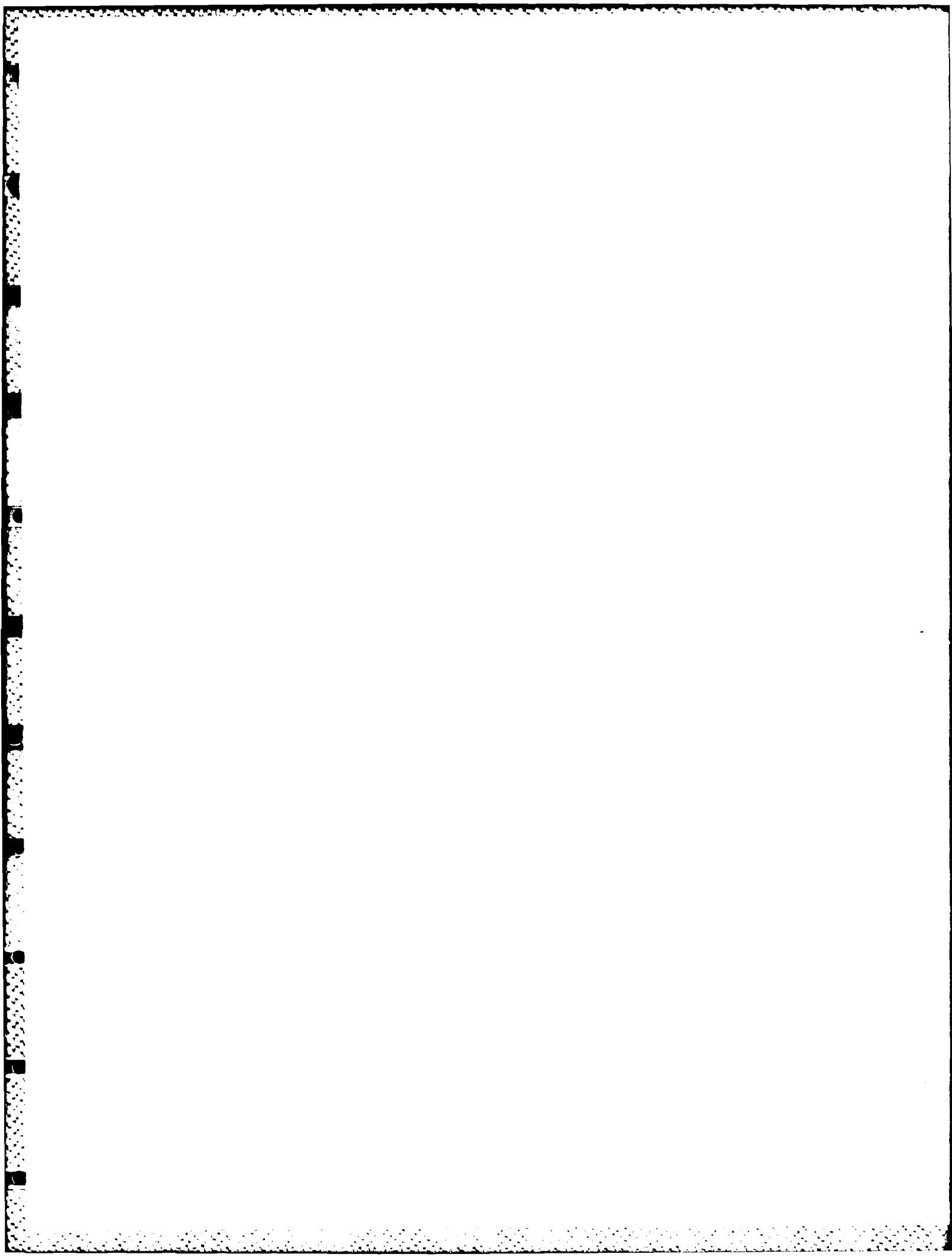
A. ANALYTICAL DERIVATIVE VERSUS FINITE DIFFERENCES

The far-zone electric fields predicted by each of these methods for computing the second derivative are in relative agreement, but the input admittances and execution times differ. The finite difference calculation takes less cpu time, but the resultant input admittance differs by 23 percent from the admittance calculated with the analytical second derivative.

B. CONJUGATE GRADIENT VERSUS IMSL LIBRARY ROUTINE

The results of the conjugate gradient and IMSL routines for the current, admittance, and far field are equal, but the routines differ in memory requirements and execution times. The IMSL routine takes less execution time but requires more memory than the conjugate gradient routine.

Numerical results in this report should be valuable in matching the options to specific applications.



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APPENDIX

The three computer programs that are listed compute the current distribution and far-zone electric field for a center-fed antenna using Pocklington's equation and the method of moments. The programs run interactively with voltage source amplitude, phase and frequency, antenna length and radius, and far-zone distance as the input parameters.

Listing 1 evaluates the second derivative analytically and solves the matrix equation using the conjugate gradient algorithm.

Listing 2 evaluates the second derivative by finite differences and solves the matrix equation using the conjugate gradient algorithm.

Listing 3 evaluates the second derivative by finite differences and solves the matrix equation using an IMSL routine.

LISTING NO. 1

```

100 C
110 C      PROGRAM WANTCG CALCULATES THE CURRENTS ON A WIRE ANTENNA
120 C
130 C      WANTCG CALCULATES THE CURRENTS ON A WIRE ANTENNA WITH THE
140 C      SOURCE AT THE CENTER. (C) IS THE CURRENT VECTOR, (V) IS THE
150 C      APPLIED VOLTAGE VECTOR AND OPERAT IS THE INTEGRAL
160 C      OPERATOR SUBROUTINE. WANTCG SOLVES FOR THE
170 C      CURRENTS USING THE CONJUGATE GRADIENT METHOD.
180 C      PROGRAM WANTCG(INPUT,TAPES=INPUT,OUTPUT,TAPE6=OUTPUT)
190 C      PARAMETER(NDIM = 70)
200 C      PARAMETER(NDIM2 =-NDIM)
210 C      DIMENSION CMOD(NDIM),CARG(NDIM),VMOD(NDIM),VARG(NDIM)
220 C      COMPLEX C(NDIM),PSI(NDIM2:NDIM),V(NDIM),VA,COEFF,E,COEFF2
230 C      COMPLEX R(NDIM),P(NDIM),Q(NDIM)
240 C      REAL MU,L,K
250 C      COMMON PI,K,MU,EPS,W
260 C      OPEN(UNIT=4,FILE='CURRENT')
270 C      REWIND 4
280 C
290 C      DECLARE CONSTANTS EPS AND MU, PERMITTIVITY AND FERMEABILITY
300 C
310 C      5 EPS = 8.84194E-12
320 C      MU = 1.256637E-06
330 C      PI = 3.14159
340 C
350 C      READ IN FREQUENCY, LENGTH AND RADIUS OF THE WIRE, VOLTAGE
360 C      THE CENTER OF THE WIRE, AND THE NUMBER OF SEGMENTS.
370 C
380 C      10 WRITE(6,900)
390 C      READ *, F
400 C      WRITE(6,905)
410 C      READ *, L,A
420 C      WRITE(6,910)
430 C      15 READ *,VA
440 C      WRITE(6,915)
450 C      READ *, N
460 C      WRITE(6,916)
470 C      916 FORMAT(2X,'INPUT FAR-FIELD DISTANCE',/)
480 C      READ *,R0
490 C
500 C      CALCULATE ANGULAR FREQUENCY, WAVE NUMBER, SEGMENT LENGTH
510 C
520 C      N1 = N*(N+2)
530 C      20 W = 2*PI*F
540 C      K=W*SQRT(MU*EPS)
550 C      DL = L/(FLOAT(N) + 1.)
560 C
570 C      ASSIGN VOLTAGE VECTOR
580 C
590 C      CALL VOLTS(N,V,VA)
600 C
610 C
620 C      INITIALIZE CURRENT VECTOR
630 C      DO 25 I=1,N
640 C      C(I) = (0.,0.)
650 C      25 CONTINUE
660 C      ASSIGN IMPEDANCE MATRIX
670 C
680 C      CALL INITPSI(N,PSI,A,DL)
690 C
700 C      CALCULATE CURRENT VECTOR

```

```

710 C
720 CALL CONGRAD(N,C,V,R,P,O,PSI)
730 DO 30 I = 1,N
740 CMOD(I) = CABS(C(I))
750 CI = AIMAG(C(I))
760 CR = REAL(C(I))
770 CARG(I) = ATAN2(CI,CR)*180/PI
780 WRITE(6,920) I,CMOD(I),CARG(I)
790 30 CONTINUE
800 WRITE(4,925)N
810 925 FORMAT(I3)
820 WRITE(4,930)
830 930 FORMAT('C, MODULUS OF ')
840 WRITE(4,935)(CMOD(I),I=1,N)
850 935 FORMAT(50(E16.8,/))
860 WRITE(4,940)
870 940 FORMAT('C, ARGUMENT OF ')
880 WRITE(4,945)(CARG(I),I=1,N)
890 945 FORMAT(50(F10.3,/))
900 COEFF = (0.,1.)*SQRT(MU/EPS)*CEXP((0.,-1.)*K*RO)/(2.*PI*RO)
910 DO 56 J=0,18
920 THETA = 10.*J
930 THETAR = PI/180.*THETA
940 E = (0.,0.)
950 PHI = K*COS(THETAR)
960 COEFF2 = TAN(THETAR)*COEFF*SIN(0.5*DL*PHI)
970 DO 57 I = 1,N
980 R1 = DL*(FLOAT(I)-0.5*FLOAT(N+1))
990 E = E + C(I)*COS(PHI*R1)
1000 57 CONTINUE
1010 E = COEFF2*E
1020 EMOD = CABS(E)
1030 WRITE(6,956)THETA,EMOD
1040 WRITE(4,956)THETA,EMOD
1050 956 FORMAT(2X, 'THETA = ',F5.1,2X, 'E = ',E10.4)
1060 56 CONTINUE
1070 900 FORMAT(2X, 'INPUT FREQUENCY IN HERTZ',/)
1080 905 FORMAT(2X, 'INPUT LENGTH AND RADIUS OF THE WIRE',/)
1090 910 FORMAT(2X, 'INPUT COMPLEX VOLTAGE APPLIED TO THE CENTER OF THE',

1100 1 ' WIRE IN THE FORM (VR,VI)',/)
1110 915 FORMAT(2X, 'INPUT THE NUMBER OF SEGMENTS = ODD INTEGER',/)
1120 920 FORMAT(2X,I3,5X,E12.4,5X,F7.2)
1130 STOP
1140 END

1150 C
1160 C
1170 C SUBROUTINE VOLTS ASSIGNS VOLTAGE VECTOR
1180 C
1190 C
1200 SUBROUTINE VOLTS(N,V,VA)
1210 COMPLEX V(N),VA
1220 I = 0
1230 5 IF(2*I+1.EQ.N)GO TO 10
1240 V(I+1) = (0.,0.)
1250 V(N-I) = (0.,0.)

```

```

1260      I = I + 1
1270      GO TO 5
1280 10    V(I+1)=VA
1290      RETURN
1300      END
1310 C
1320 C
1330 C      CONGRAD ITERATES TO THE SOLUTION VECTOR C
1340 C
1350 C
1360      SUBROUTINE CONGRAD(N,C,V,R,P,O,PSI)
1370      COMPLEX C(N),V(N),R(N),P(N),O(N),PSI(-N:N)
1380      CALL SQUARE(N,V,V2)
1390      CALL OPERAT(N,C,PSI,O)
1400      J = 0
1410      DO 100 I=1,N
1420          R(I) = O(I)-V(I)
1430 100    CONTINUE
1440      CALL SQUARE(N,R,R2)
1450      ERROR = R2/V2
1460      IF(ERROR.LT.1E-8)GO TO 800
1470      CALL COPERAT(N,R,PSI,O)
1480      CALL SQUARE(N,O,B)
1490      IF(B.LT.1E-08)GO TO 2
1500      B = 1/B
1510      GO TO 3
1520 2      B = 1.E+08
1530 3      CONTINUE
1540      DO 200 I=1,N
1550          P(I) = -B*O(I)
1560 200    CONTINUE
1570      CALL OPERAT(N,P,PSI,O)
1580      CALL SQUARE(N,O,T)
1590      IF(T.LT.1E-8)GO TO 5
1600      T = 1/T
1610      GO TO 4
1620 5      T = 1.E+08
1630 6      WRITE(6,900)J,ERROR
1640 900    FORMAT(2X,'ITERATION',13,2X,'ERROR = ',E10.4 )
1650 1      J = J+1
1660      DO 300 I=1,N
1670          C(I) = C(I)+T*P(I)
1680 300    CONTINUE
1690      CALL OPERAT(N,P,PSI,O)
1700      DO 400 I=1,N
1710          R(I) = R(I)+T*O(I)
1720 400    CONTINUE
1730      CALL OPERAT(N,C,PSI,O)
1740      DO 15 I=1,N
1750          O(I) = O(I) - V(I)
1760 15     CONTINUE
1770      CALL SQUARE(N,O,ERROR)
1780      ERROR = ERROR/V2
1790      IF(ERROR.LT.1E-8)GO TO 800
1800      CALL COPERAT(N,R,PSI,O)

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```

1810      CALL SQUARE(N,D,B)
1820      IF(B.LT.1E-8)GO TO 18
1830      B = 1/B
1840      GO TO 19
1850  18  B = 1.E+08
1860  19  CONTINUE
1870      DO 500 I=1,N
1880          F(I) = F(I)-B*D(I)
1890  500  CONTINUE
1900      CALL OPERAT(N,P,PSI,D)
1910      CALL SQUARE(N,D,T)
1920      IF(T.LT.1E-8)GO TO 16
1930      T = 1/T
1940      GO TO 17
1950  16  T = 1.E+0  1960  17  WRITE(6,900)J,ERROR
1970      IF(J.LT.100)GO TO 1
1980      WRITE(6,930)
1990  930  FORMAT(2X,'FAILED TO CONVERGE AFTER 100 ITERATIONS')
2000      GO TO 801
2010  800  CONTINUE
2020      WRITE(6,900)J,ERROR
2030      WRITE(6,920)
2040  920  FORMAT(2X,'THE ANSWER IS')
2050  801  RETURN
2060      END
2070      SUBROUTINE GAUSS(FCN,D,R,U,N,PSI)
2080  C
2090  C          96 POINT GAUSSIAN RULE INTEGRATION
2100  C
2110      COMPLEX Z,PSI,FCN,PSI1,PSI2
2120      DIMENSIONAA(48),W(48)
2130      DATA A/.99968950E00, .99836438E00, .99598184E00, .99254390E00,
2140  1 .98805413E 00, .98251726E 00, .97593917E 00, .96832683E 00,
2150  1 .95968829E 00, .95003272E 00, .93937034E 00, .92771246E 00,
2160  1 .91507142E 00, .90146064E 00, .88689452E 00, .87138851E 00,
2170  1 .85495903E 00, .83762351E 00, .81940031E 00, .80030874E 00,
2180  1 .78036904E 00, .75960234E 00, .73803064E 00, .71567681E 00,
2190  1 .69256454E 00, .66871831E 00, .64416340E 00, .61892584E 00,
2200  1 .59303236E 00, .56651042E 00, .53938811E 00, .51169418E 00,
2210  1 .48345797E 00, .45470942E 00, .42547899E 00, .39579765E 00,
2220  1 .36569686E 00, .33520852E 00, .30436494E 00, .27319881E 00,
2230  1 .24174316E 00, .21003131E 00, .17809688E 00, .14597371E 00,
2240  1 .11369585E 00, .81297495E-01, .48812985E-01, .16276745E-01 /
2250      DATA W/.79679207E-03, .18539608E-02, .29107318E-02, .39645543E-02,
2260  1 .50142027E-02, .60585455E-02, .70964708E-02, .81268769E-02,
2270  1 .91486712E-02, .10160771E-01, .11162102E-01, .12151605E-01,
2280  1 .13128230E-01, .14090942E-01, .15038721E-01, .15970563E-01,
2290  1 .16885480E-01, .17782502E-01, .18660680E-01, .19519081E-01,
2300  1 .20356797E-01, .21172940E-01, .21966644E-01, .22737070E-01,
2310  1 .23483399E-01, .24204842E-01, .24900633E-01, .25570036E-01,
2320  1 .26212341E-01, .26826867E-01, .27412963E-01, .27970008E-01,
2330  1 .28497411E-01, .28994614E-01, .29461090E-01, .29896344E-01,
2340  1 .30299915E-01, .30671376E-01, .31010333E-01, .31316426E-01,
2350  1 .31589331E-01, .31828759E-01, .32034456E-01, .32206205E-01,

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2360      1 .32343823E-01, .32447164E-01, .32516119E-01, .32550614E-01/
2370      NPOINT = 48
2380      PSI = (0.,0.)
2390      G = U/2./FLOAT(N)
2400      DO 2 I = 1,N
2410      Z = (0.,0.)
2420      DO 1 K = 1,NPOINT
2430      ARG A = G*(A(K) + 2*I-1.)
2440      ARG B = G*(-A(K) + 2*I-1.)
2450      Z = Z + (FCN(ARG A,D,R) + FCN(ARG B,D,R))*W(K)
2460      1 CONTINUE
2470      PSI = PSI + Z
2480      2 CONTINUE
2490      PSI1 = G*PSI
2500      PSI = (0.,0.)
2510      G = -G
2520      DO 4 I = 1,N
2530      Z = (0.,0.)
2540      DO 3 K = 1,NPOINT
2550      ARG A = G*(A(K) + 2*I-1.)
2560      ARG B = G*(-A(K) + 2*I-1.)
2570      Z = Z + (FCN(ARG A,D,R) + FCN(ARG B,D,R))*W(K)
2580      3 CONTINUE
2590      PSI = PSI + Z
2600      4 CONTINUE
2610      PSI2 = G*PSI
2620      PSI = PSI1 - PSI2
2630      RETURN
2640      END
2650 C
2660 C
2670 C      INITPSI CALCULATES THE PSI VALUES
2680 C
2690 C
2700      SUBROUTINE INITPSI(N,PSI,A,DL)
2710      COMPLEX PSI(-N:N),CINT,GFUNCT,F
2720      REAL K,MU
2730      EXTERNAL CINT,AFUNCT,BFUNCT,GFUNCT
2740      COMMON PI,K,MU,EPS,W
2750      U=0.5*DL
2760      F = DL/((0.,-1.)*W*4.*PI*EPS)
2770      DO 1 I=-N,N
2780      D = I*DL
2790      CALL GAUSS(CINT,D,A,U,1,PSI(I))
2800      PSI(I) = F*PSI(I)
2810      1 CONTINUE
2820      RETURN
2830      END
2840 C
2850 C
2860 C      CINT CALCULATES THE COMPLEX INTEGRAND
2870 C
2880 C
2890      COMPLEX FUNCTION CINT(ARG,D1,A1)
2900      COMPLEX GFUNCT,B,D

```

```

2910      REAL K
2920      COMMON PI,K
2930      A = K**2
2940      B = (0.,-1.)*K/(BFUNCT(ARG,D1,A1)**.5)
2950      C = -(1 + (K**2)*AFUNCT(ARG,D1))/BFUNCT(ARG,D1,A1)
2960      D = 3*(0.,1.)*K*AFUNCT(ARG,D1)/(BFUNCT(ARG,D1,A1)**1.5)
2970      E = 3*AFUNCT(ARG,D1)/(BFUNCT(ARG,D1,A1)**2)
2980      CINT = (A + B + C + D + E)*GFUNCT(ARG,D1,A1)
2990      RETURN
3000      END

3010 C
3020 C
3030      FUNCTION AFUNCT(ARG,D)
3040      AFUNCT = (ARG-D)**2
3050      RETURN
3060      END

3070 C
3080 C
3090      FUNCTION BFUNCT(ARG,D,A1)
3100      BFUNCT = AFUNCT(ARG,D) + A1**2
3110      RETURN
3120      END

3130 C
3140 C
3150 C          GFUNCT CALCULATES THE GREEN/UNCTION
3160 C
3170 C
3180      COMPLEX FUNCTION GFUNCT(ARG,D,A1)
3190      REAL K
3200      COMMON PI,K
3210      R = SQRT(BFUNCT(ARG,D,A1))
3220      GFUNCT = CEXP((0.,-1.)*K*R)/R
3230      RETURN
3240      END

3250 C
3260 C
3270 C          COPERAT IS THE ADJOINT OPERATOR
3280 C
3290 C
3300      SUBROUTINE COPERAT(N,R,PSI,O)
3310      COMPLEX PSI(-N:N),R(N),O(N)
3320      1 CONTINUE
3330      DO 200 I = 1,N
3340          O(I) = (0.,0.)
3350          DO 100 J=1,N
3360              M = I-J
3370              O(I) = O(I) + CONJG(PSI(M))*R(J)
3380      100 CONTINUE
3390      200 CONTINUE
3400      RETURN
3410      END

3420 C
3430 C
3440 C          SQUARE MULTIPLIES A VECTOR BY ITS COMPLEX CONJUGATE
3450 C

```



```

1460 C
1470 SUBROUTINE SCALAR(N,D1,D2)
1480 COMPLEX D1,D2
1490 D1=0.
1500 DO 100 I=1,N
1510 D1 = D2 + D1(1)*COS(D1/I)
1520 100 CONTINUE
1530 RETURN
1540 END
1550 C
1560 C
1570 C OPERAT IS THE INTEGRAL OPERATOR
1580 C
1590 C
1600 C
1610 SUBROUTINE OPERAT(N,C,PSI,D)
1620 COMPLEX PSI(1:N),D,C(1:N),D(1:N)
1630 DO 100 I=1,N
1640 Q(I) = (0.,0.)
1650 DO 100 J=1,N
1660 M = I+J
1670 Q(I) = Q(I) + PSI(M)*C(J)
1680 100 CONTINUE
1690 CONTINUE
1700 RETURN
1710 END

```

LISTING NO. 2

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100 C
110 C      PROGRAM WANTED CALCULATES THE CURRENTS ON A WIRE ANTENNA
120 C
130 C      WANTED CALCULATES THE CURRENTS ON A WIRE ANTENNA WITH THE
140 C      SOURCE AT THE CENTER. (V) IS THE CURRENT VECTOR, (V) IS THE
150 C      APPLIED VOLTAGE VECTOR AND OPERAT IS THE INTEGRAL
160 C      OPERATOR SUBROUTINE. WANTED SOLVES FOR THE
170 C      CURRENTS USING THE CONJUGATE GRADIENT METHOD.
180 C      PROGRAM WANTED: INPUT, TAPES=INPUT, OUTPUT, TAPES=OUTPUT)
190 C      PARAMETER (NDIM = 70)
200 C      PARAMETER (NDIM2 = NDIM)
210 C      DIMENSION CMOD (NDIM), CARG (NDIM), VMOD (NDIM), PSI (NDIM)
220 C      COMPLEX C (NDIM), PSI (NDIM2:NDIM), VAND4 (NDIM), COEFF2
230 C      COMPLEX R (NDIM), P (NDIM), Q (NDIM2:NDIM2:NDIM)
240 C      REAL MU, L, R
250 C      COMMON PI, L, R, W
260 C      OPEN (UNIT=1, FILE='CURRENT')
270 C
280 C
290 C      DECLARE CONSTANTS EPS AND MU, PERMITTIVITY AND PERMEABILITY
300 C
310 C      EPS = 8.854184E-12
320 C      MU = 1.256637E-06
330 C      PI = 3.14159
340 C
350 C      READ IN FREQUENCY, LENGTH AND RADIUS OF THE WIRE, VOLTAGE
360 C      THE CENTER OF THE WIRE, AND THE NUMBER OF SEGMENTS.
370 C
380 C      WRITE (5, 100)
390 C      READ *, F
400 C      WRITE (5, 200)
410 C      READ *, L, R
420 C      WRITE (5, 300)
430 C      READ *, VA
440 C      WRITE (5, 400)
450 C      READ *, N
460 C      WRITE (5, 500)
470 C      FORMAT (1X, 'INPUT WIRE FIELD DISTANCE, ')
480 C      READ *, R2
490 C
500 C      CALCULATE APPROXIMATE WAVELENGTH, WAVE NUMBER, SEGMENT LENGTH
510 C
520 C      W = 2*PI/F
530 C      W = 2*PI/F
540 C      F = 1/(2*PI*W)
550 C      DL = L/2/N
560 C
570 C      ASSIGN VOLTAGE VECTOR
580 C
590 C      ALL VOLTS (N, V, VA)
600 C
610 C
620 C      INITIALIZE CURRENT VECTOR
630 C      DO 25 I=1, N
640 C        C(I) = (0., 0.)
650 C      25 CONTINUE
660 C
670 C      ASSIGN IMPEDANCE MATRIX
680 C
690 C      CALL INITESI (N, PSI, R, DL, L)
700 C
710 C      CALCULATE CURRENT VECTOR

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```

710 C
720 CALL CONGRAD(N,C,V,R,F,U,Z)
730 DO 30 I = 1,N
740 CMOD(I) = CABS(C(I))
750 CI = AIMAG(C(I))
760 CR = REAL(C(I))
770 CARG(I) = ATAN2(CI,CR)*180/PI
780 WRITE(6,920) I,CMOD(I),CARG(I)
790 30 CONTINUE
900 WRITE(4,925)N
910 925 FORMAT(I3)
820 WRITE(4,930)
830 930 FORMAT('C, MODULUS OF ')
840 WRITE(4,935)(CMOD(I),I=1,N)
850 935 FORMAT(50(E16.8,/,))
860 WRITE(4,940)
970 940 FORMAT('C, ARGUMENT OF ')
980 WRITE(4,945)(CARG(I),I=1,N)
890 945 FORMAT(50(F10.3,/,))
900 COEFF = (0.,1.)*SQRT(MU/EP0)*DEXP((0.,-1.)*F*F0)/(2.*PI*R0)
910 DO 56 J=0,18
920 THETA = 10.*J
930 THETAR = PI/180.*THETA
940 E = (0.,0.)
950 PHI = R*COS(THETAR)
960 COEFF2 = TAN(THETAR)*COEFF*SIN(0.5*DL*PHI)
970 DO 57 I = 1,N
980 R1 = DL*(FLOAT(I)-0.5*FLOAT(N+1))
990 E = E + C(I)*COS(PHI+R1)
1000 57 CONTINUE
1010 E = COEFF2*E
1020 EMOD = CABS(E)
1030 WRITE(6,956)THETA,EMOD
1040 WRITE(4,956)THETA,EMOD
1050 956 FORMAT(2X, THETA = ,F5.1,2X, E = ,E10.4)
1060 56 CONTINUE
1070 900 FORMAT(2X, INPUT FREQUENCY IN HERTZ ,/)
1080 905 FORMAT(2X, INPUT LENGTH AND RADIUS OF THE WIRE ,/)
1090 910 FORMAT(2X, INPUT COMPLEX VOLTAGE APPLIED TO THE CENTER OF THE
1100 1 WIRE IN THE FORM (VR,VI),/)
1110 915 FORMAT(2X, INPUT THE NUMBER OF SEGMENTS = ODD INTEGER ,/)
1120 920 FORMAT(2X,I3,5X,E12.4,5X,F7.2)
1130 STOP
1140 END
1150 C
1160 C
1170 C SUBROUTINE VOLTS ASSIGNS VOLTAGE VECTOR
1180 C
1190 C
1200 SUBROUTINE VOLTS(N,V,VA)
1210 COMPLEX V(N),VA
1220 I = 0
1230 5 IF(2*I+1.EQ.N)GO TO 10
1240 V(I+1) = (0.,0.)
1250 V(N-I) = (0.,0.)

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```

1260      I = I + 1
1270      GO TO 5
1280 10    V(I+1)=VA
1290      RETURN
1300      END
1310 C
1320 C
1330 C      CONGRAD ITERATED TO THE SOLUTION VECTOR U
1340 C
1350 C
1360      SUBROUTINE CONGRAD(N,C,V,R,P,D,Z)
1370      COMPLEX C(N),V(N),R(N),P(N),D(N),Z(-N:N)
1380      CALL SQUARE(N,V,V2)
1390      CALL OPERAT(N,C,Z,D)
1400      J = 0
1410      DO 100 I=1,N
1420          R(I) = I
1430 100    CONTINUE
1440      CALL SQUARE(N,R,R2)
1450      ERROR = R2/V2
1460      IF (ERROR.LT.1E-9) GO TO 300
1470      CALL COERAT(N,R,Z,D)
1480      CALL SQUARE(N,D,B)
1490      IF (B.LT.1E-03) GO TO 2
1500      B = 1/B
1510      GO TO 3
1520 2      B = 1.E+08
1530 3      CONTINUE
1540      DO 200 I=1,N
1550          P(I) = -B*D(I)
1560 200    CONTINUE
1570      CALL OPERAT(N,P,Z,D)
1580      CALL SQUARE(N,D,T)
1590      IF (T.LT.1E-8) GO TO 5
1600      T = 1/T
1610      GO TO 4
1620 5      T = 1.E+08
1630 4      WRITE(6,900)J,ERROR
1640 900    FORMAT(2X, 'ITERATION ',I3,2X, 'ERROR = ',E10.4)
1650      J = J+1
1660      DO 300 I=1,N
1670          C(I) = C(I)+T*P(I)
1680 300    CONTINUE
1690      CALL OPERAT(N,P,Z,D)
1700      DO 400 I=1,N
1710          R(I) = R(I)+T*D(I)
1720 400    CONTINUE
1730      CALL OPERAT(N,C,Z,D)
1740      DO 15 I=1,N
1750          D(I) = D(I) - V(I)
1760 15      CONTINUE
1770      CALL SQUARE(N,D,ERROR)
1780      ERROR = ERROR/V2
1790      IF (ERROR.LT.1E-8) GO TO 300
1800      CALL COERAT(N,R,Z,D)

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1810      CALL SQUARE(N,D,B)
1820      IF(D.LT.1E-8)GO TO 19
1830      B = 1/B
1840      GO TO 19
1850 18   B = 1.E+08
1860 19   CONTINUE
1870      DO 500 I=1,N
1880          F(I) = F(I)/B*D(I)
1890 500   CONTINUE
1900      CALL OPERAT(N,F,Z,U)
1910      CALL SQUARE(N,D,F)
1920      IF(T.LT.1E-8)GO TO 16
1930      T = 1/T
1940      GO TO 17
1950 16   T = 1.E+08
1960 17   WRITE(6,900)J,ERROR
1970      IF(J.LT.100)GO TO 1
1980      WRITE(6,920)
1990 930   FORMAT(2X,'FAILED TO CONVERGE AFTER 100 ITERATIONS')
2000      GO TO 801
2010 800   CONTINUE
2020      WRITE(6,900)J,ERROR
2030      WRITE(6,920)
2040 920   FORMAT(2X,'THE ANSWER IS ')
2050 801   RETURN
2060      END
2070      SUBROUTINE GAUSS(FCN,D,R,U,N,PSI)
2080 C
2090 C          96 POINT GAUSSIAN RULE INTEGRATION
2100 C
2110      COMPLEX Z,PSI,FCN,PSI1,PSI2
2120      DIMENSION A(48),W(48)
2130      DATA A/.99968950E00,.99836438E00,.99598184E00,.99254390E00,
2140      1 .98805413E 00,.98251726E 00,.97593917E 00,.96832683E 00,
2150      1 .95968829E 00,.95003272E 00,.93937034E 00,.92771246E 00,
2160      1 .91507142E 00,.90146064E 00,.88689452E 00,.87138851E 00,
2170      1 .85495903E 00,.83762351E 00,.81940031E 00,.80030874E 00,
2180      1 .78036904E 00,.75960234E 00,.73803064E 00,.71567681E 00,
2190      1 .69256454E 00,.66871831E 00,.64416340E 00,.61892584E 00,
2200      1 .59303236E 00,.56651042E 00,.53938811E 00,.51169418E 00,
2210      1 .48345797E 00,.45470942E 00,.42547899E 00,.39579765E 00,
2220      1 .36569686E 00,.33520852E 00,.30436494E 00,.27319881E 00,
2230      1 .24174316E 00,.21003131E 00,.17809688E 00,.14597371E 00,
2240      1 .11369585E 00,.81297495E-01,.48812985E-01,.16276745E-01 /
2250      DATA W/.79679207E-03,.18539608E-02,.29107318E-02,.39645543E-02,
2260      1 .50142027E-02,.60585455E-02,.70964708E-02,.81268769E-02,
2270      1 .91486712E-02,.10160771E-01,.11162102E-01,.12151605E-01,
2280      1 .13128230E-01,.14090942E-01,.15038721E-01,.15970563E-01,
2290      1 .16885480E-01,.17782502E-01,.18660680E-01,.19519081E-01,
2300      1 .20356797E-01,.21172940E-01,.21966644E-01,.22737070E-01,
2310      1 .23483399E-01,.24204842E-01,.24900633E-01,.25570036E-01,
2320      1 .26212341E-01,.26826867E-01,.27412963E-01,.27970008E-01,
2330      1 .28497411E-01,.28994614E-01,.29461090E-01,.29896344E-01,
2340      1 .30299915E-01,.30671376E-01,.31010333E-01,.31316426E-01,
2350      1 .31589331E-01,.31828759E-01,.32034456E-01,.32206205E-01,

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```

2360      1 .00043823E-01, .00447164E-01, .02916119E-01, .02550614E-01/
2370      NPOINT = 48
2380      PSI = (0.,0.)
2390      G = U/2./FLOAT(N)
2400      DO 2 I = 1,N
2410          Z = (0.,0.)
2420          DO 1 I = 1,NPOINT
2430              ARGA = G*(A(I) + 2*I-1.)
2440              ARGB = G*(-A(I) + 2*I-1.)
2450              Z = Z + (FCN(ARGA,D,R) + FCN(ARGB,D,R))*W(I)
2460          1 CONTINUE
2470          PSI = PSI + Z
2480          2 CONTINUE
2490          PSI1 = G*PSI
2500          PSI = (0.,0.)
2510          G = -G
2520          DO 4 I = 1,N
2530              Z = (0.,0.)
2540              DO 3 K = 1,NPOINT
2550                  ARGA = G*(A(K) + 2*I-1.)
2560                  ARGB = G*(-A(K) + 2*I-1.)
2570                  Z = Z + (FCN(ARGA,D,R) + FCN(ARGB,D,R))*W(K)
2580              3 CONTINUE
2590              PSI = PSI + Z
2600          4 CONTINUE
2610          PSIC = G*PSI
2620          PSI = PSI1 - PSIC
2630          RETURN
2640          END
2650 C
2660 C
2670 C      INITPSI CALCULATES THE PSI VALUES
2680 C
2690 C
2700      SUBROUTINE INITPSI(N,PSI,A,DL,Z)
2710      COMPLEX PSI(-N:N),CINT,PSIA,PSIB,PSIC,PSID,PSIE,Z(-N:N)
2720      REAL R,MU
2730      EXTERNAL CINT
2740      COMMON PI,K,MU,EPS,W
2750      U=0.5*DL
2760      DO 1 I=-N,N
2770          D = I*DL
2780          CALL GAUSS(CINT,D,A,U,1,PSI(I))
2790      1 CONTINUE
2800      DO 200 J = 1,N
2810          DO 100 I = 1,N
2814              M = I-J
2815              PSIA = PSI(M)/DL
2816              PSIB = PSIA
2817              M = I-J+1
2818              PSIC = PSI(M)/DL
2819              M = I-J-1
2820              PSID = PSI(M)/DL
2821              PSIE = PSIA
2822          M = I-J

```

```

2827      Z(M) = (0.,1.)*W*MU*DL**2.*PSIA
2828      Z(M) = Z(M) + 1./W*(0.,1.)*EPS.*PSIB*(PSIC+PSID+PSIE)
2829 100    CONTINUE
2830 200    CONTINUE
2831      RETURN
2832      END
2840 C
2850 C
2860 C      CINT CALCULATES THE COMPLEX INTEGRAND
2870 C
2880 C
2890      COMPLEX FUNCTION CINT(ARG,D,A)
2891      REAL A
2892      COMMON P1,P
2893      R = SQRT(A**2 + (ARG-D)**2)
2894      CINT = CEXP((0.,-1.)*P*R)/(4*P1*R)
2895      RETURN
2896      END
2950 C
2960 C
2970 C      COPERAT IS THE ADJOINT OPERATOR
2980 C
3000      SUBROUTINE COPERAT(N,P,Z,D)
3010      COMPLEX R(N),Q(N),Z(-N:N)
3020      DO 100 I = 1,N
3030          Q(I) = (0.,0.)
3040          DO 100 J = 1,N
3050              M = I-J
3060              Q(I) = Q(I) + CONJG(Z(M))*R(J)
3070 100    CONTINUE
3080 200    CONTINUE
3090      RETURN
3100      END
3110 C
3120 C
3130 C      SQUARE MULTIPLIES A VECTOR BY ITS COMPLEX CONJUGATE
3140 C
3150 C
3160 C      SUBROUTINE SQUARE(N,U1,U2)
3170      COMPLEX U1(N)
3180      U2=0.
3190      DO 100 I=1,N
3200          U2 = U2 + U1(I)*CONJG(U1(I))
3210 100    CONTINUE
3220      RETURN
3230      END
3240 C
3250 C
3260 C      OPERAT IS THE INTEGRAL OPERATOR
3270 C
3280 C
3290 C
3300      SUBROUTINE OPERAT(N,U,Z,D)
3310      COMPLEX U(N),Q(N),Z(-N:N)
3320      DO 100 I=1,N
3330          Q(I) = (0.,0.)
3340          DO 100 J = 1,N
3350              M = I-J
3360              Q(I) = Q(I) + Z(M)*U(J)
3370 100    CONTINUE
3380 200    CONTINUE
3390      RETURN
3400      END

```


LISTING NO. 3

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100 C
110 C      PROGRAM WANTMOM CALCULATES THE CURRENTS ON A WIRE ANTENNA
120 C
130 C      WANTMOM CALCULATES THE CURRENTS ON A WIRE ANTENNA WITH THE
140 C      SOURCE AT THE CENTER. (Z) IS THE IMPEDANCE MATRIX, (C) IS
150 C      THE CURRENT VECTOR, AND (V) IS THE APPLIED VOLTAGE VECTOR.
160 C      WANTMOM SOLVES FOR THE CURRENTS USING THE METHOD OF MOMENTS.
170 C
180 C      PROGRAM WANTMOM(INPUT,TAPE5=INPUT,OUTPUT,TAPE6=OUTPUT)
190 C      PARAMETER(NDIM = 70)
200 C      PARAMETER(NDIM2 = NDIM**2,NDIM3 = -NDIM,NDIM4 = NDIM*(NDIM+2))
210 C      DIMENSION CMOD(NDIM),CARG(NDIM),VMOD(NDIM),VARG(NDIM)
220 C      COMPLEX Z(NDIM2),C(NDIM),PSI(NDIM3:NDIM),V(NDIM),VA
230 C      COMPLEX WA(NDIM4),WK(NDIM),COEFF,COEFF2,E
240 C      REAL MU,L,K
250 C      COMMON PI,K,MU,EPS,W
260 C      OPEN(UNIT=4,FILE='CURRENT')
270 C      REWIND 4
280 C
290 C      DECLARE CONSTANTS EPS AND MU, PERMITTIVITY AND PERMEABILITY
300 C
310 C      5 EPS = 8.84194E-12
320 C      MU = 1.256637E-06
330 C      PI = 3.14159
340 C
350 C      READ IN FREQUENCY, LENGTH AND RADIUS OF THE WIRE, VOLTAGE
360 C      THE CENTER OF THE WIRE, AND THE NUMBER OF SEGMENTS.
370 C
380 C      10 WRITE(6,900)
390 C      READ *, F
400 C      WRITE(6,905)
410 C      READ *, L,A
420 C      WRITE(6,910)
430 C      15 READ *,VA
440 C      WRITE(6,915)
450 C      READ *, N
460 C      )
470 C      916 FORMAT(2X,'INPUT FAR-FIELD DISTANCE',/)
480 C      READ *,RO
490 C
500 C      CALCULATE ANGULAR FREQUENCY, WAVE NUMBER, SEGMENT LENGTH
510 C
520 C      N1 = N*(N+2)
530 C      20 W = 2*PI*F
540 C      K=W*SQRT(MU*EPS)
550 C      DL = L/(FLOAT(N) + 1.)
560 C
570 C      ASSIGN VOLTAGE VECTOR
580 C
590 C      CALL VOLTS(N,V,VA)
600 C
610 C      ASSIGN IMPEDANCE MATRIX
620 C
630 C      CALL IMP(N,Z,A,DL,PSI)
640 C
650 C      CALCULATE CURRENT VECTOR
660 C
670 C      CALL LEQS(Z,N,N1,V,WA,WK)
680 C      DO 30 I = 1,N
690 C      CMOD(I) = CABS(V(I))
700 C      CI = AIMAG(V(I))

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710      CR = REAL(V(I))
720      CARG(I) = ATAN2(CI,CR)*180/PI
730      WRITE(6,920) I,CMOD(I),CARG(I)
740 30    CONTINUE
750      DO 40 I = 1,N
760        C(I) = V(I)
770 40    CONTINUE
780      WRITE(4,925)N
790 925  FORMAT(I3)
800      WRITE(4,930)
810 930  FORMAT('C, MODULUS OF ')
820      WRITE(4,935)(CMOD(I),CMOD(I),I=1,N)
830 935  FORMAT(50(E16.8,/))
840      WRITE(4,940)
850 940  FORMAT('C, ARGUMENT OF ')
860      WRITE(4,945)(CARG(I),CARG(I),I=1,N)
870 945  FORMAT(50(F10.3,/))
880      COEFF = (0.,1.)*SQRT(MU/EPS)*CEXP((0.,-1.)*K*RO)/(2.*PI*RO)
890      DO 56 J=0,18
900        THETA = 10.*J
910        THETAR = PI/180.*THETA
920        E = (0.,0.)
930        PHI = K*COS(THETAR)
940        COEFF2 = TAN(THETAR)*COEFF*SIN(0.5*DL*PHI)
950        DO 57 I = 1,N
960          R1 = DL*(FLOAT(I)-0.5*FLOAT(N+1))
970          E = E + C(I)*COS(PHI*R1)
980 57    CONTINUE
990        E = COEFF2*E
1000       EMOD = CABS(E)
1010       WRITE(6,956)THETA,EMOD
20        WRITE(4,956)THETA,EMOD
1030 956  FORMAT(2X, 'THETA = ',F5.1,2X, 'E = ',E10.4)
1040 56    CONTINUE
1050 900  FORMAT(2X, 'INPUT FREQUENCY IN HERTZ',/)
1060 905  FORMAT(2X, 'INPUT LENGTH AND RADIUS OF THE WIRE',/)
1070 910  FORMAT(2X, 'INPUT COMPLEX VOLTAGE APPLIED TO THE CENTER OF THE',

1080      1 WIRE IN THE FORM (VR,VI) ,/)
1090 915  FORMAT(2X, 'INPUT THE NUMBER OF SEGMENTS = ODD INTEGER',/)
1100 920  FORMAT(2X,I3,5X,E12.4,5X,F7.2)
1110      STOP
1120      END
1130 C
1140 C
1150 C      SUBROUTINE VOLTS ASSIGNS VOLTAGE VECTOR
1160 C
1170 C
1180      SUBROUTINE VOLTS(N,V,VA)
1190      COMPLEX V(N),VA
1200      I = 0
1210 5      IF 2*I+1.EQ.N GO TO 10
1220      V(I+1) = (0.,0.)
1230      V(N-I) = (0.,0.)
1240      I = I + 1
1250      GO TO 5

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```

1260 10  V(I+1)=VA
1270      RETURN
1280      END
1290 C
1300 C
1310 C          SUBROUTINE IMP ASSIGNS IMPEDANCE MATRIX
1320 C
1330 C
1340      SUBROUTINE IMP(N,Z,A,DL,PSI)
1350      COMPLEX Z(N,N),PSI(-N:N),PSIA,PSIB,PSIC,PSID,PSIE,CINT
1360      REAL K,MU
1370      EXTERNAL CINT
1380      COMMON PI,K,MU,EPS,W
1390 C
1400      U = 0.5*DL
1410 C          INTEGRATE FROM -U TO U TO GET PSIS
1420      DO 1 I = -N,N
1430          D = I*DL
1440 C
1450 C          D IS THE DISTANCE FROM INTEGRATING POINT, J TO OBSERVATION
1460 C          POINT, I.
1470 C
1480          CALL GAUSS(CINT,D,A,U,1,PSI(I))
1490 1      CONTINUE
1500      DO 200 J=1,N
1510 5      DO 100 I=1,N
1520          M = I-J
1530          PSIA = PSI(M)/DL
1540          PSIB = PSIA
1550 10      M = I-J+1
1560          PSIC = PSI(M)/DL
1570          M = I-J-1
1580          PSID = PSI(M)/DL
1590          PSIE = PSIA
1600 15      Z(I,J) = (0.,1.)*W*MU*DL**2.*PSIA
1610          Z(I,J) = Z(I,J) + 1./W/(0.,1.)/EPS*(PSIB-PSIC-PSID+PSIE)
1620 C          WRITE(6,900) I,J,Z(I,J)
1630 100      CONTINUE
1640 200      CONTINUE
1650 900      FORMAT(2X,'Z(',I3,',',I3,',') = ',2E15.8)
1660      RETURN
1670      END
1680 C
1690 C
1700 C          CINT CALCULATES THE COMPLEX INTEGRAND
1710 C
1720 C
1730      COMPLEX FUNCTION CINT(D,A,ARG)
1740      REAL K
1750      COMMON PI,K
1760      R = SQRT(A**2 + (ARG-D)**2)
1770      CINT = CEXP((0.,-1.)*K*R)/(4*PI*R)
1780      RETURN
1790      END
1800 C

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```

1810 C          LINEAR EQUATION SOLUTION
1820 C
1830          SUBROUTINE LEQS(Z,N,N1,V,WA,WK)
1840          COMPLEX Z(N,N),V(N,1),WA(N1),WK(N)
1850          CALL LEQ2C(Z,N,N,V,1,N,0,WA,WK,IER)
1860          RETURN
1870          END
1880          SUBROUTINE GAUSS(FCN,D,R,U,N,PSI)
1890 C
1900 C          96 POINT GAUSSIAN RULE INTEGRATION
1910 C
1920          COMPLEX Z,PSI,FCN,PSI1,PSI2
1930          DIMENSION A(48),W(48)
1940          DATA A/.99968950E00,.99836438E00,.99598184E00,.99254390E00,
1950          1 .98805413E 00,.98251726E 00,.97593917E 00,.96832683E 00,
1960          1 .95968829E 00,.95003272E 00,.93937034E 00,.92771246E 00,
1970          1 .91507142E 00,.90146064E 00,.88689452E 00,.87138851E 00,
1980          1 .85495903E 00,.83762351E 00,.81940031E 00,.80030874E 00,
1990          1 .78036904E 00,.75960234E 00,.73803064E 00,.71567681E 00,
2000          1 .69256454E 00,.66871831E 00,.64416340E 00,.61892584E 00,
2010          1 .59303236E 00,.56651042E 00,.53938811E 00,.51169418E 00,
2020          1 .48345797E 00,.45470942E 00,.42547899E 00,.39579765E 00,
2030          1 .36569686E 00,.33520852E 00,.30436494E 00,.27319881E 00,
2040          1 .24174316E 00,.21003131E 00,.17809688E 00,.14597371E 00,
2050          1 .11369585E 00,.81297495E-01,.48812985E-01,.16276745E-01 /
2060          DATA W/.79679207E-03,.18539608E-02,.29107318E-02,.39645543E-02,

2070          1 .50142027E-02,.60585455E-02,.70964708E-02,.81268769E-02,
2080          1 .91486712E-02,.10160771E-01,.11162102E-01,.12151605E-01,
2090          1 .13128230E-01,.14090942E-01,.15038721E-01,.15970563E-01,
2100          1 .16885480E-01,.17782502E-01,.18660680E-01,.19519081E-01,
2110          1 .20356797E-01,.21172940E-01,.21966644E-01,.22737070E-01,
2120          1 .23483399E-01,.24204842E-01,.24900633E-01,.25570036E-01,
2130          1 .26212341E-01,.26826867E-01,.27412963E-01,.27970008E-01,
2140          1 .28497411E-01,.28994614E-01,.29461090E-01,.29896344E-01,
2150          1 .30299915E-01,.30671376E-01,.31010333E-01,.31316426E-01,
2160          1 .31589331E-01,.31828759E-01,.32034456E-01,.32206205E-01,
2170          1 .32343823E-01,.32447164E-01,.32516119E-01,.32550614E-01/
2180          NPOINT = 48
2190          PSI = (0.,0.)
2200          G = U/2./FLOAT(N)
2210          DO 2 I = 1,N
2220          Z = (0.,0.)
2230          DO 1 K = 1,NPOINT
2240          ARG = G*(A(K) + 2*I-1.)
2250          ARG = G*(-A(K) + 2*I-1.)
2260          Z = Z + (FCN(D,R,ARG) + FCN(D,R,ARG))*W(K)
2270          1 CONTINUE
2280 C          WRITE(6,990) I,K,FCN(D,R,ARG),FCN(D,R,ARG)
2290          PSI = PSI + Z
2300          2 CONTINUE
2310          PSI1 = G*PSI
2320          990 FORMAT(2X,'I=',I2,2X,'K=',I2,2X,'F(A)=' ,2E10.4,2X,'F(B)=' ,2E10.
4)
2330          PSI = (0.,0.)
2340          G = -G
2350          DO 4 I = 1,N

2360          Z = (0.,0.)
2370          DO 3 K = 1,NPOINT
2380          ARG = G*(A(K) + 2*I-1.)
2390          ARG = G*(-A(K) + 2*I-1.)
2400          Z = Z + (FCN(D,R,ARG) + FCN(D,R,ARG))*W(K)
2410          3 CONTINUE
2420          PSI = PSI + Z
2430          4 CONTINUE
2440          PSI2 = G*PSI
2450          PSI = PSI1 - PSI2
2460          RETURN
2470          END

```

```

2360      Z = (0.,0.)
2370      DO 3 K = 1,NPOINT
2380      ARG = G*(A(K) + 2*I-1.)
2390      ARG = G*(-A(K) + 2*I-1.)
2400      Z = Z + (FCN(D,R,ARG) + FCN(D,R,ARG))*W(K)
2410 3     CONTINUE
2420      PSI = PSI + Z
2430 4     CONTINUE
2440      PSI2 = G*PSI
2450      PSI = PSI1 - PSI2
2460      RETURN
2470      END

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LABORATORY OPERATIONS

The Laboratory Operations of The Aerospace Corporation is conducting experimental and theoretical investigations necessary for the evaluation and application of scientific advances to new military space systems. Versatility and flexibility have been developed to a high degree by the laboratory personnel in dealing with the many problems encountered in the nation's rapidly developing space systems. Expertise in the latest scientific developments is vital to the accomplishment of tasks related to these problems. The laboratories that contribute to this research are:

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